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Indian Standard

COAXIAL COMMUNICATION CABLES

PART 1-112 ELECTRICAL TEST METHODS — TEST FOR RETURN LOSS (UNIFORMITY OF IMPEDANCE)

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Wires, Cables, Waveguides and Accessories Sectional Committee, LITD 6

NATIONAL FOREWORD

This Indian Standard (Part 1-112) which is identical with IEC 61196-1-112 : 2006 'Coaxial communication cables — Part 1-112: Electrical test methods — Test for return loss (uniformity of impedance)' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Wires, Cables, Waveguides and Accessories Sectional Committee and approval of the Electronics and Information Technology Division Council.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appear to the following International Standard for which Indian Standard also exists. The corresponding Indian Standard which is to be substituted in its place is listed below along with its degree of equivalence for the edition indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 61196-1 : 2005 Coaxial communication cables — Part 1: Generic specification — General, definitions and requirements	IS/IEC 61196-1 : 2005 Coaxial communication cables: Part 1 Generic specification — General, definitions and requirements	Identical

Only English language text has been retained while adopting it in this Indian Standard, and as such the page numbers given here are not the same as in IEC Standard.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

COAXIAL COMMUNICATION CABLES

PART 1-112 ELECTRICAL TEST METHODS — TEST FOR RETURN LOSS (UNIFORMITY OF IMPEDANCE)

1 Scope

This part of IEC 61196 applies to coaxial communications cables. It specifies test methods for determining the return loss (uniformity of impedance).

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61196-1, *Coaxial communication cables – Part 1: Generic specification – General, definitions and requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61196-1 apply.

4 Principle

Return loss is useful for quantifying the level (amount) of the reflected signal in a coaxial cable. Return loss combines the effects of reflections due to both the deviation from the nominal impedance of the cable under test (such as 50 Ω or 75 Ω) and structural effects and is specified when system performance is the primary interest.

When calibration of the network analyser and S-parameter unit is performed relative to the reference impedance, the return loss is:

$$RL = -20 \log \left| S_{11} \right|$$

where

$$S_{11} = \frac{\sqrt{P_\mathrm{r}}}{\sqrt{P_\mathrm{i}}}$$

where

P_r is the reflected power;

P_i is the incident power.

Stated in terms of the impedances the return loss is given by

$$RL = -20 \log \left| \frac{Z_\mathrm{T} - Z_\mathrm{R}}{Z_\mathrm{T} + Z_\mathrm{R}} \right|$$

where

RL is the return loss, in dB;

Z_T is the measured complex impedance, in ohms (Ω), obtained from terminated cable measurements where the distant end is terminated in Z_R;

Z_R is the reference impedance, in ohms (Ω), (50 Ω, 75 Ω, or as appropriate).

5 Test method

5.1 Test equipment

A Vector Network Analyser (VNA) capable of performing S_{11}/S_{22} measurements and a calibration kit with calibration standards (open, short, load).

5.2 Preparation of test specimen

Precision test connectors with small inherent reflections shall be fitted on both ends of the test specimen to allow direct connection to the network analyser and/or, terminating load.

5.3 Principle of error correction (calibration) of test equipment

A detailed description of the error correction (calibration) procedure is given in the manual of the VNA.

Return-loss measurements are strongly dependent on the directivity of the directional bridge or coupler (E_D), frequency response tracking (E_R) and source match (E_S). These 3 errors are related to the actual data (S_{11a}) and the measured data (S_{11m}) by

$$S_{11m} = E_D + \frac{S_{11a} \cdot E_R}{1 - E_S \cdot S_{11a}} \tag{1}$$

If the 3 errors are known, a corrected return loss of the device under test can be obtained. The errors are found by measuring the system using 3 independent standards with known characteristics. These standards are a calibrated load, open-circuit and short-circuit terminations.

Measuring a calibrated load (S_{11a} = 0) results in

$$S_{11load} = E_D \tag{2}$$

Measuring a short circuit (S_{11a} = –1) results in

$$S_{11short} = E_D + \frac{-E_R}{1 + E_S} \tag{3}$$

The open circuit gives the third independent condition. Open connectors have parasite capacitances, thus a specially designed open circuit with known phase ϕ_O is used, which results in

$$S_{11open} = E_D + \frac{1\angle\phi_O \cdot E_R}{1 - E_S \cdot 1\angle\phi_O} \tag{4}$$

From the above 3 equations the 3 errors (in ideal systems $E_D = 0$, $E_S = 0$ and $E_R = 1$) can be calculated. Finally, the return loss can be calculated.

The error correction (calibration) shall be done at the plane where the cable under test (CUT) will be connected for the measurement. All adaptors and impedance matching circuits used shall be included in the error correction (calibration) procedure.

5.4 Number of measuring points

VNAs measure at discrete frequency points. In order to get the correct measurement for narrowband peaks in the return loss, the frequency spacing between 2 neighbouring measurement frequencies shall not be too large.

The bandwidth of reflection peaks is dependent on the cable attenuation. The higher the attenuation, the larger the bandwidth, and consequently the larger could be the frequency spacing between 2 measurement points. The cable attenuation for RF cables is frequency-dependent and increases with frequency. Thus, finally, the maximum permitted frequency spacing between two measuring points increases with the measurement frequency[1,2].

The frequency spacing Δf between any 2 measuring points shall be:

$$\Delta f \leq 1{,}4 \cdot \frac{300 \cdot v_r}{868{,}6 \cdot \pi} \cdot a\,(f) \cdot \sqrt{10^{\frac{\Delta a_{r,f}}{10}} - 1} \qquad (5)$$

where

Δf is the maximum permitted frequency spacing between 2 measurement points, in MHz;

$a(f)$ is the cable attenuation at the measured frequency, in dB/100 m;

v_r is the relative velocity;

$\Delta a_{r,f}$ is the maximum permitted error which can be caused by the frequency spacing, in dB;

1,4 is the factor which takes into account the difference between theoretical and practical investigations.[3]

If not specified otherwise, the maximum permitted error caused by the frequency spacing shall be $\Delta a_{r,f} \leq 1$ dB.

5.5 Length of cable under test

The change in return loss for small frequency deviations from the resonance frequency of reflection peaks does not depend on the cable length. However, the maximum value of the peak is length-dependent. With decreasing test length, the return loss increases. The change is described by $\Delta a_{r,L}$.

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[1] 46XA/Sec105/INF: Proposal for the frequency spacing of return loss measurements of RF cables.

[2] 46XA/Sec104/INF: Requirement on the frequency spacing for the measurement of the return loss of RF cables.

[3] 46XA/BE0122/INF: Calculations and measurements concerning the number of points resp. frequency spacing.

$$\Delta a_{\mathrm{r,L}} = a_{\mathrm{r}}(L_2) - a_{\mathrm{r}}(L_1) = 20\log_{10}\left(\frac{1-\mathrm{e}^{-2\alpha L_1}}{1-\mathrm{e}^{-2\alpha L_2}}\right) \tag{6}$$

where

L is the length of the CUT, in m;

α is the cable attenuation at the measured frequency, in Np/m;

$a_{\mathrm{r}}(L)$ is the return loss for a specific length L.

Therefore, the length of the CUT shall be stated in the test report.

5.6 Procedure

5.6.1 General

The return loss (S_{11} or S_{22}) of the CUT shall be measured with the VNA over the specified frequency range.

The requirements for frequency spacing according to 5.4 shall be fulfilled. Several methods are possible, some of which are mentioned hereunder.

- Single frequency band method, where the frequency spacing between 2 measurement points is constant over the whole frequency band.
- Subinterval method, where the frequency band to be measured is divided into several subintervals. The frequency spacing is constant in each subinterval but is different from one subinterval to another.
- Continuously varying frequency spacing method, where the frequency spacing between 2 measuring points is varied continuously as a function of the cable attenuation at the frequency to be measured.

Any other method which fulfils the requirements for frequency spacing according to 5.4 is permitted. It is up to the user to choose an appropriate method.

5.6.2 Single frequency band method

Some VNA allow the measurement of an infinite number of frequency points. In this case, the measurement could be made in one sweep with the following number of measuring points.

$$NOP \geq \frac{f_{\mathrm{max}} - f_{\mathrm{min}}}{\Delta f} + 1 \tag{7}$$

where

NOP is the minimum number of frequency points necessary for a single sweep over the whole specified frequency interval;

Δf is the maximum permitted frequency spacing between 2 measurement points, in MHz, calculated for f_{min};

f_{min} is the lowest frequency of the interval to be measured, in MHz;

f_{max} is the highest frequency of the interval to be measured, in MHz.

5.6.3 Subinterval method

In the case of VNA with a limited number of frequency points, the frequency interval to be measured may be divided into subintervals, where the frequency span of the subinterval can be calculated by:

$$f_{\mathrm{max}} - f_{\mathrm{min}} \leq (NOP - 1) \cdot \Delta f \qquad (8)$$

where

NOP is the number of frequency points available by the network analyser;

Δf is the maximum permitted frequency spacing between 2 measurement points, in MHz, calculated for f_{min};

f_{min} is the lowest frequency of the subinterval to be measured, in MHz;

f_{max} is the highest frequency of the subinterval to be measured, in MHz.

5.6.4 Continuously varying frequency spacing method

Instead of measuring a swept frequency range, single frequencies could be measured. The distance between 2 measuring points could then continuously be varied from one test frequency to another as a function of the cable attenuation. The maximum permitted frequency spacing between 2 successive measurement frequencies is calculated according to 5.4.

6 Test report

The test report shall give the following test conditions:

- temperature in degrees;
- length of CUT, in m;
- maximum error due to frequency spacing effect, in dB;
- analyser settings such as sweep time, IF bandwidth, averaging factor.

The test report shall for each specified frequency band record the worst value of the return loss and the corresponding frequency.

7 Requirement

The values shall not exceed the requirements of the relevant sectional or detail specification.

Annex A
(informative)

Requirement on the frequency spacing for the measurement of the return loss of r.f. cables

A.1 General

Nowadays, the frequency-dependent characteristics of coaxial cables are measured by the means of VNA, which measure at discrete frequencies. In order to get the correct measure for narrowband peaks in return loss, the frequency spacing between 2 neighbouring measurement frequencies shall not be too large.

IEC 61196-1:1995 required a number of measurement points depending on the frequency span and the sample length:

$$n \geq \frac{5 \cdot (f_2 - f_1) l}{(150 \cdot v_r)} \tag{A.1}$$

where

f is the frequency, in MHz;

l is the sample length, in m;

v_r is the relative velocity.

This equation results in high numbers, for example, a

- frequency range of 5 MHz to 3 GHz (which is common for CATV cables);
- solid PE dielectric (worst case);
- cable length of 100 m

results in 15 140 measurement points. Usually, the return loss (of CATV) cables is measured on production lengths of 1 000 m which then results in numbers which are 10 times higher. Considering coaxial cables, which are used up to 12 GHz or 20 GHz (for example, semi-rigid cables or RG cables) will result in at least 36 000 measurement points for a length of 100 m. However, standard VNA in general only provide 1 601 points per frequency sweep. Although there exist software solutions which in principle provide infinite measurement points, it is of interest to know how many measurement points are needed to get a correct result.

This annex investigates the bandwidth of resonances in return-loss measurements. The bandwidth increases with the cable attenuation, i.e. with the frequency. With an increasing resonance bandwidth, the frequency spacing could be increased, and, thus, the number of measurement points could be decreased. It is also demonstrated that the bandwidth of the resonance peak is independent on the cable length.

An investigation has been carried out by K. Erdel[4]. He modelled the reflections by discontinuously distributed parallel capacitances which are only applicable for certain causes of the reflection, but, in reality, continuously distributed reflections also exist.

A.2 Physical basics

A.2.1 General

The critical points in return-loss curves are those with peaks. Those resonant peaks are caused by periodic variations of the characteristic impedance and could be of very small bandwidth.

Also, for homogenous cables with concentrated deviations of the characteristic impedance (for example, at the cable ends), one needs to be careful. In this case, the frequency response of the return loss is changing periodically with a high repetition rate, especially for long distances and cables with low attenuation. But, in general, the reflections caused by the mismatch of the cable are fewer compared to the reflections caused by structural variations along the cable length.

A.2.2 Return-loss model

A.2.2.1 General

The model illustrated in Figure A.1 describes the inhomogeneities of the characteristic impedance by reflections. Summing up the reflected waves of each single reflection propagating to the beginning of the cable results in the reflection coefficient at the cable input.

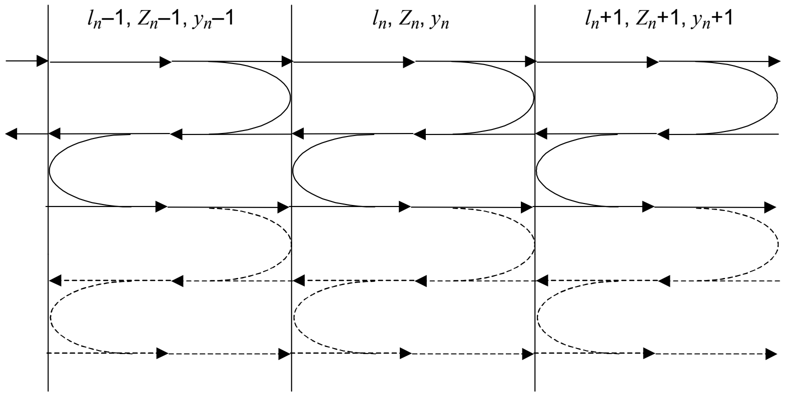

Figure A.1 – Reflection model

A.2.2.2 Solution taking into account all multiple reflections

A wave propagating from a transmission line n with the impedance Z_n to a transmission line n + 1 with the impedance Z_{n+1} is reflected with the reflection factor $r_{n,n+1}$. Due to the reflection, the wave behind the point of the reflection is changed by the factor (1 + $r_{n,n+1}$). Taking into account all multiple reflections and the wave propagation effect results in a geometric series. For the resulting wave in the backward direction (the sum of the reflected waves) the following is obtained:

---

[4] *Auswirkung periodischer Kabelstörstellen auf die Übertragung von Breitbandsignalen*; K. Erdel; Siemens Forsch.- u. Entwickl.- Ber. Bd. 5 (1976) Nr. 4, Springer-Verlag 1976.

$$B_n = \frac{\sum u_\mathrm{r}}{u_\mathrm{i}} = \frac{\left(1 - r_{n,n-1}{}^2\right) r_{n,n+1} \mathrm{e}^{-2\gamma_n l_n}}{1 - r_{n,n-1} r_{n,n+1} \mathrm{e}^{-2\gamma_n l_n}} - r_{n,n-1} \tag{A.2}$$

$$r_{n,n-1} = \frac{Z_{n-1} - Z_n}{Z_{n-1} + Z_n} \tag{A.3}$$

$$r_{n,n+1} = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n} \tag{A.4}$$

and for the resulting wave in the forward direction, the following is obtained:

$$F_n = \frac{\sum u_\mathrm{f}}{u_\mathrm{i}} = \frac{\left(1 - r_{n,n-1}\right)\left(1 + r_{n,n+1}\right) \mathrm{e}^{-2\gamma_{n\mathrm{i}} l_{n\mathrm{i}}}}{1 - r_{n,n-1} r_{n,n+1} \mathrm{e}^{-2\gamma_n l_n}} \tag{A.5}$$

These equations can be directly applied for the calculation of the resulting backward and forward propagating waves of homogenous cables with concentrated deviations of the characteristic impedance (for example, at the cable ends).

A.2.2.3 Approximate solution

The above equations are not useful for reflections (continuously) distributed along the cable length. However, on condition of small local reflections, multiple reflections can be neglected. In this case, the distributed reflections can be integrated along the cable length to get the resulting reflection coefficient at the input of the cable.

$$\underline{r}(x) = \lim_{\Delta x \to 0} \frac{Z(x + \Delta x) - Z(x)}{Z(x + \Delta x) + Z(x)} = \frac{Z'(x)}{2Z(x)} \tag{A.6}$$

For the wave related to the cable input, the wave propagation effect should be taken into account. The reflection coefficient at the cable input is then described by

$$\underline{r}_0(x) = \underline{r}(x) \mathrm{e}^{-2\gamma x} \tag{A.7}$$

For the resulting reflection coefficient (with neglect of multiple reflections), the following is obtained:

$$\underline{r}_\mathrm{res} \approx \int_{x=0}^{L} \frac{Z'(x)}{2Z(x)} \mathrm{e}^{-2\gamma x} dx \tag{A.8}$$

A sinusoidal variation of the local characteristic impedance along the cable length is assumed. Any other periodic variation could be described by a sum of sinusoidal functions (Fourier):

$$Z(x) = Z_\mathrm{m}\left(1 + \frac{\Delta Z}{Z_\mathrm{m}} \sin\left(\frac{2\pi}{\lambda_\mathrm{Z}} x\right)\right) = Z_\mathrm{m}\left(1 + \delta_\mathrm{Z} \sin\left(\frac{2\pi}{\lambda_\mathrm{Z}} x\right)\right) \tag{A.9}$$

where

Z_m is the mean characteristic impedance;

λ_Z is the geometric wavelength of the impedance variation.

$$\underline{r}(x) = \frac{Z'(x)}{2Z(x)} \approx \frac{Z'(x)}{2Z_\mathrm{m}} \tag{A.10}$$

$$\underline{r}(x) = \frac{\delta_Z}{2} \frac{2\pi}{\lambda_\mathrm{Z}} \cos\left(\frac{2\pi}{\lambda_\mathrm{Z}} x \right) \tag{A.11}$$

For the resulting reflection coefficient at the input of the cable, the following is obtained:

$$\underline{r} = \frac{\delta_Z}{2} \frac{2\pi}{\lambda_\mathrm{Z}} \int_{x=0}^{L} \cos\left(\frac{2\pi}{\lambda_\mathrm{Z}} x \right) \cdot \mathrm{e}^{-2\gamma x} \, dx \tag{A.12}$$

The cable length is always longer than the geometric wavelength of the impedance variation $L >> \lambda_\mathrm{Z}$. Thus, L/λ_Z can be considered as an integer number. Taking this into account results in

$$\underline{r} = \frac{\delta_\mathrm{Z}}{2} \cdot \frac{1}{\dfrac{\gamma}{\pi/\lambda_\mathrm{Z}} + \dfrac{\pi/\lambda_\mathrm{Z}}{\gamma}} \cdot \left(1 - \mathrm{e}^{-2\gamma L}\right) \tag{A.13}$$

The factor in brackets describes the length dependency of the reflection coefficient. The reflection coefficient is maximum for an infinite length.

Resonance is given if

$$\left| \frac{\gamma}{\pi/\lambda_\mathrm{Z}} \right| = 1 \qquad \text{i.e.} \qquad \alpha^2 + \beta^2 = \left(\frac{\pi}{\lambda_\mathrm{Z}} \right)^2 \tag{A.14}$$

with $\alpha\lambda_\mathrm{Z} << \beta\lambda_\mathrm{Z}$ one gets $\beta\lambda_\mathrm{Z} = \pi$.

In this case, the reflection coefficient has its only absolute maximum. In practice, harmonic reflection peaks are often observed. In this case, the impedance variation is not sinusoidal, but any other periodic function which could be (according to Fourier) split in several sinusoidal components, where each of them creates a resonance peak.

$$r_\mathrm{max} = \frac{\delta_Z}{2} \cdot \frac{\pi}{2\alpha\lambda_\mathrm{Z}} \left(1 - \mathrm{e}^{-2\alpha L}\right) \tag{A.15}$$

Instead of using the phase constant, β, it is more convenient to use the electrical wavelength $\lambda_\mathrm{e} = 2\pi/\beta$. Then, we get at resonance

$$\lambda_\mathrm{e,res} = \frac{2\lambda_\mathrm{Z}}{\sqrt{1 + \left(\dfrac{\alpha\lambda_\mathrm{Z}}{\pi} \right)^2}} \approx 2\lambda_\mathrm{Z} \tag{A.16}$$

$$f_{\text{res}} = \frac{c_0}{\lambda_{\text{e,res}}\sqrt{\varepsilon_{\text{r}}}} = \frac{c_0}{2\lambda_{\text{Z}}\sqrt{\varepsilon_{\text{r}}}}\sqrt{1+\left(\frac{\alpha\lambda_{\text{Z}}}{\pi}\right)^2} \approx \frac{c_0}{2\lambda_{\text{Z}}\sqrt{\varepsilon_{\text{r}}}} \qquad \text{(A.17)}$$

The relation between the reflection coefficient and the return loss is given by

$$a_{\text{r}} = -20\,\lg\left|\underline{r}\right| = 20\,\lg\left|\frac{1}{\underline{r}}\right| \qquad \text{(A.18)}$$

$$a_{\text{r}} = 20\,\lg\left\{\frac{\delta_Z}{2}\cdot\left|\frac{\gamma}{\pi/\lambda_{\text{Z}}}+\frac{\pi/\lambda_{\text{Z}}}{\gamma}\right|\right\} - 20\,\lg\left|1-\text{e}^{-2\gamma L}\right| \qquad \text{(A.19)}$$

and at the resonance, the following minimum return loss is obtained:

$$a_{\text{r,min}} = 20\,\lg\left\{\frac{2}{\delta_Z}\cdot\frac{2\alpha\lambda_Z}{\pi}\right\} - 20\,\lg\left(1-\text{e}^{-2\alpha L}\right) \qquad \text{(A.20)}$$

If the frequency deviates from the resonance frequency, than the return loss changes by $\Delta a_{\text{r,f}}$. Assuming that α and β do not change significantly for small frequency deviations and $\alpha\lambda_{\text{Z}}$<<1 results in

$$f = f_{\text{res}}\left(1 \pm \delta_{\text{f}}\right) \quad \text{and} \quad \delta_{\text{f}} << 1 \qquad \text{(A.21)}$$

$$\Delta a_{\text{r,f}} = a_{\text{r}} - a_{\text{r,min}} = 20\,\lg\frac{\pi}{2\alpha\lambda_{\text{Z}}}\left|\frac{\alpha\lambda_{\text{Z}}}{\pi} + j\left(1+\delta_{\text{f}}\right) + \frac{1}{\frac{\alpha\lambda_{\text{Z}}}{\pi} + j\left(1+\delta_{\text{f}}\right)}\right| \qquad \text{(A.22)}$$

$$\Delta a_{\text{r,f}} \approx 20\,\lg\frac{\pi}{2\alpha\lambda_{\text{Z}}}\left|\frac{\alpha\lambda_{\text{Z}}}{\pi}\left(1+\frac{1}{\left(1+\delta_{\text{f}}\right)^2}\right) + j\left(\left(1+\delta_{\text{f}}\right) - \frac{1}{1+\delta_{\text{f}}}\right)\right|$$

$$\Delta a_{\text{r,f}} \approx 20\,\lg\left\{\frac{\pi}{2\alpha\lambda_{\text{Z}}}\left|2\frac{\alpha\lambda_{\text{Z}}}{\pi}\left(1-\delta_{\text{f}}\right) + j2\delta_{\text{f}}\right|\right\}$$

$$\Delta a_{\text{r,f}} \approx 20\,\lg\left\{\frac{\pi}{2\alpha\lambda_{\text{Z}}}\sqrt{\left(2\frac{\alpha\lambda_{\text{Z}}}{\pi}\right)^2 + 4\delta_{\text{f}}^{\,2}}\right\} = 10\,\lg\left\{1+\left(\frac{\pi}{\alpha\lambda_{\text{Z}}}\delta_{\text{f}}\right)^2\right\}$$

and finally:

$$\delta_{\text{f}} = \left|\frac{f - f_{\text{res}}}{f_{\text{res}}}\right| \approx \frac{\alpha\lambda_{\text{Z}}}{\pi}\sqrt{10^{\frac{\Delta a_{\text{r,f}}}{10}} - 1} \qquad \text{(A.23)}$$

where

α is the attenuation of the cable, in Np/m, at the measured frequency;

$\Delta a_{\text{r,f}}$ is the deviation of the return loss from the maximum value at the resonant frequency;

δ_f is the relative deviation from the resonant frequency;

λ_z is the geometric wavelength of the periodic impedance variation (see equation (A.17));

f is the measured frequency, in Hz;

f_{res} is the resonant frequency caused by periodic impedance variations (see equation (A.17)).

Note that $2\delta_f$ is the $\Delta a_{r,f}$ bandwidth of the resonant peak (see Figure A.2).

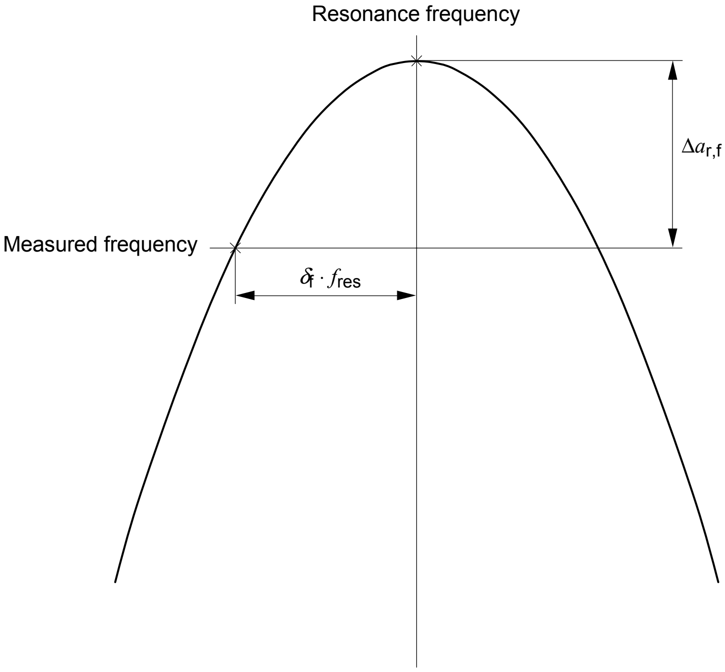

Figure A.2 – Resonance peak

We have seen that the change in return loss for small frequency deviations from the resonance frequency does not depend on the cable length. However, the maximum value of the peak is length-dependent. From equation (A.20), it can be seen that with decreasing test length, the return loss increases . The change is described by $\Delta a_{r,L}$:

$$\Delta a_{r,L} = a_r(L_2) - a_r(L_1) = 20\lg\left(\frac{1-e^{-2\alpha L_1}}{1-e^{-2\alpha L_2}}\right) \tag{A.24}$$

with α (Np/m).

Example:

A coaxial cable with the following values:

Z_m = any value; $\delta_Z = 10^{-3}$; λ_Z = 1 m; ε_r = 2,28; α = 10 dB/100 m = 11,5 mNp/m

results in

$a_{r,min}$ = 23,3 dB and $\lambda_{e,res}$ = 2 m or f_{res} = 100 MHz.

An increase of the return loss by 3 dB (1 dB) is observed for a frequency deviation of

$\delta_\mathrm{f} \approx$ 0,365 % (0,186 %) or 365 kHz (186 kHz).

The return loss measured on a 100 m length is 0,9 dB higher compared to an infinite length.

A.3 Comparison between the theoretical and practical results

In the following, the above-mentioned theoretical return loss model has been compared with practical measurements.

Based on the theoretical investigations, the theoretical frequency deviation versus the error of the return loss of a resonance peak is given by the following formula:

$$\delta_\mathrm{f} = \frac{150 \cdot v_\mathrm{r}}{868{,}6 \cdot \pi} a(f) \sqrt{10^{\Delta a_\mathrm{r,f}} - 1} \qquad \text{(A.25)}$$

Several deviations were measured on different cables having several peaks and the results shown in Figure A.3 were obtained.

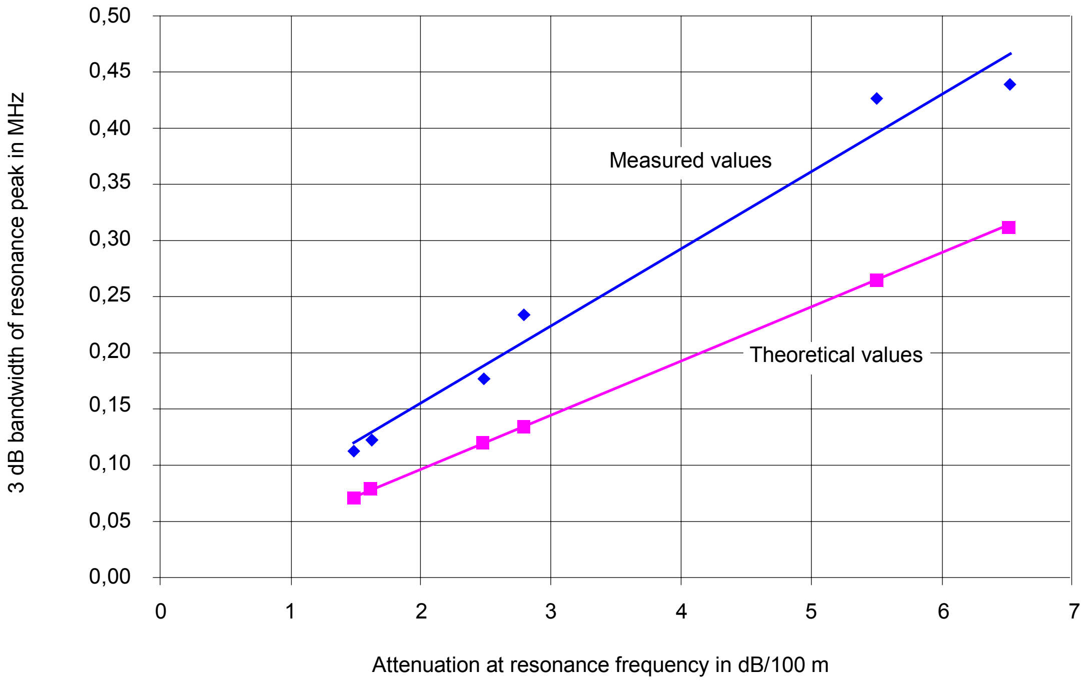

Figure A.3 – Comparison of theoretical and measured 3 dB bandwidths of resonance peaks

From these results, it can be noted that

a) the experimental values are proportional to the attenuation of the cable at the resonance frequency as expected in theory;

b) the experimental frequency deviations are larger than those calculated. The ratio between experimental and theoretical values is about 1,4. The difference between the experimental and theoretical deviations can be explained by the fact that, in practice, the variation of the impedance along the cable is not purely sinusoidal.

Thus, a correction factor of 1,4 is introduced resulting in a permitted frequency spacing of

$$\Delta f \leq 1{,}4 \cdot \frac{300 \cdot v_r}{868{,}6 \cdot \pi} \cdot a(f) \cdot \sqrt{10^{\frac{\Delta a_{\mathrm{r,f}}}{10}} - 1} \qquad \text{(A.26)}$$

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